QUALITY UNCERTAINTY AND GRAIN MERCHANDISING RISK: VOMITOXIN IN SPRING WHEAT

D. Demcey Johnson, William W. Wilson, and Matthew Diersen

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Highlights

A mathematical programming model is used developed to demonstrate implications of a random quality factor, vomitoxin, for spatial flows and merchandising risk. The model is developed from a seller's perspective using crop quality and market data from 1993 and 1994, years of severe Vomitoxin infestations in the U.S. spring wheat crop. Vomitoxin poses major risks for grain traders because of regulatory (FDA) limits, sampling difficulties, and imprecise measurement. If a shipment is rejected because of excess vomitoxin, it must be sold at a reduced price to an alternative buyer. These implicit discounts influence precautionary efforts by sellers to ensure that contract specifications are satisfied.

The model is structured as a blending problem. There are nine wheat supply regions, each with different quality attributes. Seven contracts are used by specific buyers with delivery to or through Minneapolis or the Pacific Northwest (PNW), each with different prices and quality requirements. The objective is to maximize the value of wheat sales net of transportation costs. Inclusion of a random quality factor, vomitoxin, complicates the analysis. The distribution of vomitoxin (mean and variance) varies geographically as well as between crop years. Traders can assemble grain from different regions and, through blending, influence the probability that shipments will receive the full price, avoiding discounts for excess vomitoxin. Relationships among these endogenous probabilities, market price spreads, and contract specifications are of central interest in model simulations.

Following are some of the major findings:

- *Vomitoxin disrupted "normal" spatial flow patterns in 1993, according to results of base case simulations. Large amounts of wheat from eastern crop reporting districts were exported via the PNW, while wheat from the western and central districts was sold to domestic millers and shipped east. The failure of selected PNW buyers to specify contract limits for vomitoxin was critical to this flow pattern.*

- *A comparison of alternative simulations suggests that vomitoxin (and associated price discounts) lowered the value of North Dakota wheat production by about $86 million in 1993. This is in addition to the value of yield losses sustained that year. Impacts were largest in eastern districts, where vomitoxin was especially severe.*

- *Merchandisers must be concerned with the distribution of vomitoxin in purchased grain. When vomitoxin levels are subject to greater uncertainty (i.e., have larger variances), the seller incurs larger risks of rejected shipments. To illustrate the significance of different levels of mean and variance, the model was simulated with a range of values in an individual crop district. Results confirm that wheat values at points of origin (i.e., prices received by producers) are inversely related to both the mean and variance of vomitoxin.*

- *Buyers of wheat compete against one another not only on the basis of price, but through quality specifications. Specifying abnormally tight requirements, not matched by competing contracts, should reduce the geographical region in which a buyer is competitive. However, in the context of our model, with multiple quality factors and competing contracts, the effects of contract tightening are not always easy to anticipate.*

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INTRODUCTION

In many grain markets, price relationships, merchandising strategies and spatial flows are heavily influenced by quality factors. Foreign and domestic end-users of grain have diverse quality requirements. Supplies of quality characteristics are heterogeneous, varying by producing region and through time, depending on conditions in individual crop years. Heterogeneity in supply and demand for characteristics is a critical feature of grain handling and merchandising. Elevators segregate grain based on quality factors (such as protein or test weight) and enhance their marketing margins through blending and conditioning activities. Traders assemble grain from different producing regions, with different quality characteristics, to satisfy needs of individual buyers and to capture price premiums.

However, quality variability creates uncertainty and risks, a fact that is well recognized among grain merchandisers. Interest on this topic was heightened by recent experiences in the spring wheat and barley markets. In 1993 and 1994, weather conditions led to severe quality problems for spring-planted grains. Vomitoxin (aka deoxynivalenol), a toxic substance of mold origin (and subject to food safety regulations), was detected in high concentrations in some growing regions. Vomitoxin is an example of a quality characteristic that cannot easily be controlled by contract specifications due to sampling and measurement error. The distribution of vomitoxin also varies both geographically and through time. Such characteristics increase risks for grain traders and complicate procurement strategies for domestic and international buyers.

Grain traders make sales on the basis of contract specifications for quality characteristics. When individual characteristics are subject to large sampling or measurement error, they are viewed as random from a trading perspective. This has implications for merchandising and procurement strategies. Grain sellers weigh the probability of not meeting contract specifications (and associated price risks) when assembling grain before shipment. If, after shipment and inspection at a destination, the grain fails to meet the buyer's quality specifications, it may be discounted or (in the case of vomitoxin) forced to be sold to an alternative market at a lower price. The magnitude of this penalty will influence precautionary efforts by sellers i.e., decisions about sourcing of grain, and levels of quality characteristics before shipment, to ensure that contract specifications are satisfied. Price effects (premiums or discounts) are transmitted to country origins as traders shift their procurement in response to quality risks and changing price relationships among contracts and markets.

**Assistant professor, professor, and graduate student, respectively, in the Department of Agricultural Economics, North Dakota State University, Fargo.

Quality variability (uncertainty) creates numerous problems for end-users. Both the Office of Technology Assessment (U.S. Congress) and USDA studies (Mercier) on grain quality concluded that quality variability is a growing concern among importers. Because of the growing sophistication of buyers and competition in the international and domestic grain market, there is a trend toward greater specificity in contract terms. As contracts become more specific, buyers' procurement costs increase. In addition, procurement becomes more restricted geographically due to competitive pressures and restricted availability of specific qualities.

Importer procurement strategies i.e., the combinations of price and quality specificity, are critical factors in the spring wheat market. Some importers use more stringent contract specifications than U. S. domestic millers. The latter are accustomed to mixing and blending and can target specific producing regions for their wheat procurement. Contract specifications have considerable strategic importance, particularly in view of competition among buyers. As quality specifications become more restrictive, procurement becomes more difficult; higher prices must be bid to meet volume requirements.

These problems are not unique to wheat and vomitoxin. Similar problems exist with aflatoxin in corn and vomitoxin in barley (Wheeler). With growing awareness of food safety issues and increasing buyer sophistication, it has become increasingly important to integrate effects of quality variability into economic and strategic analyses of trade and procurement. As demonstrated in this report, the value of wheat in different geographical locations varies substantially with both the level and variability of quality characteristics, as well as with other parameters (e.g., price differentials and transportation costs) traditionally associated with spatial equilibrium.

The purpose of this report is to analyze effects of quality variability on the allocation of wheat among competing markets and contracts. The focus is on quality variability, trading risks, and competition among buyers offering different prices and contract terms. The primary quality characteristic of interest is vomitoxin, which had important effects on the upper great plains wheat and barley markets during 1993 and 1994. However, the analysis requires consideration of other quality characteristics relevant to wheat buyers. A math programming model was developed to incorporate the spatial dimensions of quality distributions, competing geographic market demands, and contract requirements and premiums/discounts for specific buyers. The model was used to evaluate the effect of quality variability and alternative buyer strategies on trade patterns and merchandising risk.

BACKGROUND

Related Studies. Policymakers, grain trading firms and agencies, and agricultural economists have analyzed issues related to grain quality. This reflects the increased perception of quality as an important factor in trade and competition. Some of the issues identified in this report were addressed in earlier studies. Waugh analyzed Canadian wheat samples to evaluate effects of grade factors on end-use performance. Hyslop analyzed the effect of grade factor levels and location on the value of wheat. They confirmed that location was an important factor determining the value of individual wheat lots.

There have been numerous studies related on grain quality with several evolving strains of literature. One analyzed the extent and effect of differentiation in the world wheat trade. These include studies by Larue and Lapan; Veeman; Wilson and Gallagher; Wilson (1989, 1994); and Wilson

and Preszler. Mercier analyzed the role of quality in wheat import decisions, based on results from a survey of international buyers. Johnson and Wilson (1995) developed an optimization model that simultaneously determined the importer's demand for quality attributes (in this case, cleaned wheat) and the exporter's supply of cleaned wheat.

Other studies have addressed issues related to the role of institutions affecting quality heterogeneity. These include the Office of Technology Assessment (U.S. Congress) and Hill. Recent research has begun to examine the economics of conditioning grain and the role of market and regulatory mechanisms in providing incentives. These include studies on wheat cleaning by Adam, Kenkel, and Anderson; Fridirici, Kiser, Schnake and Wingfield; USDA studies (summarized by Lin and Leath; Mercier and Hyberg; and Hyberg et al.); and Wilson, Scherping, Johnson, and Cobia. Johnson and Wilson (1993) developed a blending model with integrated cleaning technology at the country elevator level.

A recurring theme in these studies has been the importance of quality variability. The OTA study found that grain buyers wanted more information on end-use performance and had major concerns about the lack of uniformity in quality. The USDA survey (summarized in Mercier) of buyers indicated that wheat from both Australia and Canada was superior to U.S. in terms of quality variability and cleanliness. Concerns were raised about quality variability both within and between shipments (Mercier and Hyberg). To date, much of the U.S. research has focused on quality levels, rather than quality variability, even though both the level and variability are critical in commercial processing.[1,2] This problem was analyzed in the case of end-use performance variability by Wilson and Preszler. Their study uses a chance-constrained programming model to assess impacts of quality variability on wheat imports in the United Kingdom.

Quality Definitions. Wheat quality is conventionally described in terms of grade-determining and nongrade-determining factors. The former are easily measured and have standardized procedures for evaluation. Grade-determining factors affect the grade number assigned to particular samples using the least-factor approach.

Nongrade-determining quality factors are also important to end-users but do not affect the grades. Of particular importance in the case of wheat are protein, dockage, falling numbers, sprout damage, vitreous kernels, and vomitoxin. Protein is a proxy for gluten strength, and dockage is a measure of the amount of "easily removable" nonwheat material in a sample.

Vitreous kernels (measured in %) relates to the hard, glossy appearance of wheat and usually varies with protein content. It is judged visually by comparing wheat samples with known standards under a constant light source. Sub-classes of Hard Red Spring (HRS) wheat are determined on the basis of vitreous kernels. Falling number is a test for potential sprout damage, or premature germination. Technically, it is the number of seconds required for a plunger to fall a measured distance through a heated water and flour mixture. Higher falling number values indicate low alpha-amylase activity (i.e., sounder wheat).

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[1] In particular, large variations in quality can interrupt production schedules, increase processing costs, require additional storage, and reduce end-product quality.

[2] In large part, *total quality management* is motivated by the objective of reducing quality variability.

Vomitoxin. Sprouting of wheat has been a problem throughout the world wheat economy for many years. Untimely rains before harvest may induce sprouting of kernels. Wahl and O'Rourke reported that in some regions of the world, sprouting may occur from 3 (Canada, United Kingdom, Germany, and Finland) to 7 (Poland, Sweden, and Japan) years out of 10. Other areas commonly affected by sprout include the U.S. Pacific Northwest and Northeast. Their simulation results (using the USDA SWOPSIM model) demonstrated that overall producer revenues decrease by 4 to 10% in the United States because of sprouting.

Growing conditions during 1993 and 1994 gave rise to scab infestations in spring-planted grains. Vomitoxin is an undesirable characteristic which became a major factor in the spring wheat and barley markets.[3] This section defines vomitoxin and explains its treatment in regulations. Impacts of vomitoxin on grain merchandising and procurement are also described.

Regulations and Grades: Vomitoxin is a non-carcinogenic fusarium mycotoxin also known as DON, an acronym for "deoxynivalenol" (National Grain and Feed Association, p. 1). Unlike some toxins, it generally "does not represent a threat to public health among the general population, ... [but] sometimes produces acute temporary nausea and vomiting in humans and animals" (Milling and Baking News, p. 11). Vomitoxin is a by-product of fusarium graminearum or scab (Moore, p. 3).

Scab kernels are counted as damaged in U.S. grade standards but inference to vomitoxin is not made. Thus, vomitoxin is measured indirectly in U.S. grade standards. It is also regulated for safety reasons by the Food and Drug Administration (FDA). Although vomitoxin can be present in scabbed kernels, the presence of scab does not mean that vomitoxin is present. Nor does the scab kernel count give an accurate measure of the extent of vomitoxin. The Neogin (brand) ELISA test is widely used to measure vomitoxin. This test measures vomitoxin in ranges but is not highly accurate. More advanced testing methods provide a precise and accurate measurement (and are the methods used in this study). The drawback is their higher expense as a testing procedure.

The FDA treats vomitoxin at an "advisory level," meaning it is not subject to mandatory limits. However, the agency reserves the right to take regulatory action against persons who knowingly blend grain containing vomitoxin with clean grain--if the resulting mixture is likely to result in an end-product that significantly exceeds the advisory level necessary to protect human and animal health (NGFA, p. 5).

The previous vomitoxin advisory level was established in 1982 and was set at 2 ppm for raw grains, 1 ppm for products, and 4 ppm for feed. These were changed in September 1993 as follows: the limit on raw grains was eliminated; product limits were retained at 1 ppm; and there was a change in advisory level for feed, with different limits for individual species.

Vomitoxin Statistics: The level and variability of vomitoxin among North Dakota Crop Reporting Districts (CRDs) are shown in Tables 1 and 2 for the 1993 and 1994 crops. Vomitoxin levels in several regions had averages greater than the FDA advisory levels, particularly those in the eastern region (CRDs 3, 6, and 9). There was substantial variability both across and within CRDs. A comparison between years shows that vomitoxin was more extensive in 1993.

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[3]The technical and agronomic aspects of vomitoxin have been the subject of numerous analysis. See Minnesota Wheat Research and Promotion Council, 1993 and 1994, for a summary of this research.

Table 1. Wheat Supply and Quality Attributes by Region 1993†

ND Crop Reporting District	Nonrandom factors									Vomitoxin	
	Q	PRO	TW	SB	DK	FM	DAM	VIT	FN	μ	σ
CRD 1	35.7	13.0	60.23	1.06	1.47	0.39	0.30	84	341	0.22	0.06
CRD 2	27.8	14.6	58.63	0.75	1.68	0.15	1.10	79	362	0.65	0.69
CRD 3	40.7	14.8	55.20	1.11	1.67	0.24	4.29	69	348	4.65	2.58
CRD 4	22.4	13.8	60.02	1.15	1.21	0.04	0.54	75	379	0.33	0.30
CRD 5	32.6	14.0	58.69	1.08	1.84	0.08	1.04	70	357	1.54	2.31
CRD 6	35.7	15.0	55.95	1.35	2.40	0.12	5.44	79	398	7.35	4.00
CRD 7	27.5	14.2	59.32	1.56	3.24	0.02	0.68	83	380	0.30	0.26
CRD 8	19.9	13.9	58.94	1.44	1.57	0.03	0.80	72	379	0.96	0.84
CRD 9	32.0	14.1	57.49	1.15	2.03	0.01	3.14	79	409	6.58	3.33

† Q: quantity (mil. bu); PRO: protein (%); TW: test weight (lbs/bu); SB: shrunken and broken kernels (%); DK: dockage (%); FM: foreign material (%); DAM: damage (%); VIT: vitreous kernels (%); FN: falling number; μ: mean parts per million; σ: standard deviation. Defects are the sum of SB, FM, and DAM.

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Table 2. Wheat Supply and Quality Attributes by Region 1994

ND Crop Reporting District	Nonrandom Factors 1994									Vomitoxin	
	Q	PRO	TW	SB	DK	FM	DAM	VIT	FN	μ	σ
CRD 1	27.7	13.1	61.24	1.23	1.43	0.29	0.20	82	394	10.94	0.01
CRD 2	27.5	13.8	60.16	1.38	1.63	0.23	0.63	84	375	1.20	1.31
CRD 3	51.0	14.3	57.75	1.39	1.15	0.23	4.67	78	348	10.94	10.35
CRD 4	21.4	13.4	61.32	2.03	2.99	0.46	0.07	92	383	0.01	0.01
CRD 5	34.3	13.6	59.32	1.58	3.55	0.50	1.49	78	397	2.30	2.51
CRD 6	37.1	14.6	56.69	1.90	3.75	0.17	5.82	70	391	7.29	5.82
CRD 7	26.1	13.6	61.37	2.29	1.76	0.10	0.12	95	379	0.01	0.01
CRD 8	19.9	13.3	60.97	1.39	3.58	0.09	0.26	86	389	0.20	0.21
CRD 9	33.8	14.2	60.19	0.76	2.82	0.24	0.40	88	402	1.10	1.23

The standard deviation of vomitoxin in the samples increases with mean levels. Where vomitoxin is more prevalent, it is subject to greater uncertainty. Incidences of vomitoxin have been highly uneven. The average level of vomitoxin (weighted by production in nine CRD's) was 2.84 ppm in 1993. Ignoring CRDs 3, 6, and 9, (eastern North Dakota) the weighted average was only 0.67.

Data from crop quality surveys suggested vomitoxin is positively correlated with damage, defects, and test weight (Table 3). To control the level of vomitoxin, a buyer could use specifications for other, more easily measurable characteristics. For example, tighter specifications on damage or defects would be expected to have an impact on the level of vomitoxin in purchased grain.

Trading, Handling and Procurement: The existence of contract specification and regulatory limits for vomitoxin induced a response by the trading and handling industry. The Minneapolis Grain Exchange, the principal futures contract for HRS wheat, requires deliveries to be "fit for human consumption," which was interpreted to mean in conformance with FDA regulations. Domestic food processors initially established contract limits at 2 ppm, which were subsequently replaced by limits for vomitoxin in the product.

Importers of HRS had varying responses; however, most instituted new contract specifications. Alternative measures of Vomitoxin were used by importers shipping from the Pacific Northwest (PNW). Japan initially adopted a "scab-free" specification, defined as no scab-infected kernels using FGIS analysis. Presumably, scab free was considered equivalent to vomitoxin free. Vomitoxin was not easily testable until the FGIS tests were announced. Other importers adapted varying levels of vomitoxin in their specification, or used a more stringent specification for damage.

In this market environment substantial price discounts emerged for vomitoxin-infected wheat. Even after the September 1993 FDA announcement, traders remained concerned about the potential reaction of customers to high levels of vomitoxin. Discounts were particularly severe at points of origination.[4] This was due partly to the lack of a quick test for vomitoxin. As an alternative practical approach, many buyers chose to purchase grain from locations with low reported levels of vomitoxin, i.e., the western CRDs of North Dakota.

Discounts were largest in the immediate post-harvest period for the 1993 crop, but abated somewhat with the promulgation of new FDA regulations. Japan paid up to 27c/b ($10/mt) for scab-free wheat (Oades). The highest discount for vomitoxin was $1/b; this was reduced to 65c/b and eventually 40 to 50c/b (terminal discounts) for vomitoxin greater than 4 ppm (Milling and Baking News, Sept. 21, 1993). Discounts at country locations in North Dakota were 20c/b for Vomitoxin greater than 2 ppm (Flaskerud).

Quality: Contract Specifications and Limits. Data were collected on the specifications required by principal HRS buyers in the two principal geographic markets for this type of wheat: Minneapolis and PNW (See Table 4). The Minneapolis market comprises four contractually different segments, which are representative of most eastbound shipments of wheat from North Dakota.[5] The milling contract (*hereafter referred as domestic milling*) is that generally used by millers located in and

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[4]Pedrazza (Aug. 15, 1994).

[5]Minneapolis is the destination or transit point for about 50% of the HRS crop.

Table 3. Correlations Among Quality Characteristics, 1993 - 1994 Crop Years

	SB	FM	DAM	DEF	TWT	DOC	PRO	FN	VIT	VOM
1993 Crop Year										
SB		.01	.04	.37*	-.17*	.23*	-.17*	-.06	-.07	.02
FM			-.01	.23*	-.05	.20*	-.24	.01	-.05	-.02
DAM				.91*	-.69*	.24*	.32*	-.01	-.21*	.79*
DEF					-.69*	.34*	.17*	-.02	-.21*	.72*
TWT						-.33*	-.35*	.09	.24*	-.56*
DOC							.01	-.02	-.01	.17*
PRO								.01	.24*	.25*
FN									.23*	.24*
VIT										.03
1994 Crop Year										
SB		-0.2	.13	.46*	-.19*	.21*	-.15*	-.12	-.09	.23*
FM			.08	.26*	-.07	.21*	.13	-.06	.02	.39*
DAM				.92*	-.78*	.10	.28*	-.25*	-.46*	-.68*
DEF					-.75*	.20*	.21*	-.26	-.42*	.67*
TWT						-.30*	-.36*	.23*	.45*	-.47*
DOC							-.04	-.02	-.11	-.15
PRO								.03	.30*	.17
FN									.36*	-.25*
VIT										-.31*

* Significantly different from zero.
** The Vomitoxin correlations are only for CRDs 3, 6, and 9.

beyond Minneapolis. Domestic markets trade basis 14% protein, but individual transactions may deviate and are subject to premium/discount schedules. There are two contracts specified for *Terminal* wheat, distinguished only by levels of falling number and vomitoxin. These specifications are representative of HRS wheat exports from either Duluth/Superior or from the U.S. Gulf (which are priced basis Minneapolis).

There are several large buyers of HRS at the PNW, each with unique quality specifications. Although Japan specifies Grade No. 2, some of its factor limits call for higher quality. Most interesting are the limits on heat damage and the use of "scab-free," which implies zero tolerance for vomitoxin. Other countries specified vomitoxin at 2 ppm, consistent with previous FDA limits, or omitted a vomitoxin specification. Sprout-damage in each of the contracts is specified at 0.5% (maximum). This is the predominant type of damage in the grade standards, and sprout damage was the precursor measurement to the Falling Number test.[6] Korea and Taiwan each explicitly specify No. 1, 14.5% protein and differ only in the value of vitreous kernels and falling number. Thailand and Philippines each require No. 2 grade specifications, with Thailand requiring 15% protein. Philippines' specifications are generally looser and similar to those of other HRS buyers off the PNW. Similar information for these importers was collected for 1994 and used in one of the simulations.[7]

Public Issues: A great deal of public attention was focused on problems associated with vomitoxin (North Dakota State Wheat Commission). During 1993, an estimated 90 million bushels were lost from North Dakota's HRS crop harvest. A similar problem, though not as severe, occurred in 1994 with estimated losses at 36 million bushels.

The U.S. General Accounting Office (U.S.GAO) initiated an investigation over pricing practices. The request was to determine "why producers in these states were forced to accept steep and inconsistent discounts in prices paid for their commodities..." (U.S.GAO). "Grain buyers applied higher discounts for vomitoxin-contaminated grain to compensate for this risk" (p., 4). The study reported that high vomitoxin levels (p. 3) that may have been the result of biased sampling, as farmers and elevators chose to test grain they already suspected was contaminated.[8]

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[6]There is no specific factor limit for sprout damage in the standards; it is simply a component of total damage.

[7]Contract requirements were identical with the following exceptions: Korea's falling number specification was reduced to 330; and, dockage was specified as 0.8 for Japan and Philippines, 0.7 for Taiwan, and 1.0 for Korea and Thailand. These contracts were on an all dockage-deductible basis, with Japan allowing 0.5 dockage before deduction.

[8]The testing measure was the ELISA test which only reports a range (Moore, personal communication).

Table 4. Factor and Nonfactor Quality Requirements at Principal HRS Markets[9,10]

	MINNEAPOLIS MARKETS			PACIFIC NORTHWEST EXPORT MARKETS				
	MILL.	TERMINAL		FEED	JAPAN	KOREA	TAIWAN	THAILAND	PHILL
SUBCLASS	DNS	NS/DNS	NS/DNS	ns	NS/DNS	NS/DNS	DNS	DNS	ns
GRADE	1 (2)	2	2	4 ow[11]	2	1	1	2 ob	2 ob
FACTOR LIMITS									
Test Weight	60 (58)	57	57	54	57	58	58	57	57
Shrunken & Broken	3	5	5	12	5	3	3	5	5
Heat Damage	0.2	0.2	0.2	1	0	0.2	0.2	0.2	0.2
Sprout Damage	ns	ns	ns	ns	0.5	0.5	0.5	0.5	0.5
Foreign Material	0.4	1	1	3	1	0.5	0.5	1	1
Damage	1.5 (2)	4	4	15	4	2	2	4	4
Protein	14	14	14	ns	14	14.5	14.5	15	14
Dockage	1	ns	ns	ns	1	0.5	1	ns	ns
Vitreous Kernels	75	25	25	ns	25	25	75	75	65
Falling Number	275	250	0	ns	300	350	300	300	ns
Vomitoxin	2	2	6	ns	scab free	2	2	2	ns

[9]Figures shown are normal, or conventional, specifications. Those shown in zero indicates values adapted for 1993.
[10]Besides these the PNW export market has specific specifications for ergot, moisture, and treated seeds.
[11]ob and ow stand for "or better" and "or worse," respectively.

MODEL SPECIFICATION

The analytical model has features in common with other blending problems.[12] Grain supplies are allocated to nine regions, each with different quality characteristics. The model includes seven buyer contracts, each with different quality requirements. Grain can be assembled and blended from different origins to attain desired levels of particular characteristics. Prices in terminal markets are taken as fixed along with transport costs. The objective is to maximize expected sales revenue net of transportation costs, subject to grain availability and quality constraints.

Inclusion of a random quality factor, vomitoxin, complicates the analysis. More than other grain quality factors, vomitoxin is subject to sampling and measurement error. As a result, merchandisers can only expect to meet contract limits (e.g., no more than 2 ppm for domestic millers) in a probabilistic sense. If a shipment to a domestic or export customer is rejected because of excess vomitoxin, that wheat must be sold under an alternative contract with less stringent requirements at a reduced price. The price spread between "primary" and "secondary" contracts is equivalent to a discount for vomitoxin. The magnitudes of discounts and probabilities of avoiding discounts in different contracts are central features of the merchandising problem.

Other studies have incorporated "chance constraints" in blending models (Wilson and Preszler; St. Pierre and Harvey). In those studies, qualities of ingredients are random, but the "blend" must satisfy quality constraints with a specified probability. Formulation of our model is somewhat different. Probabilities of satisfying vomitoxin constraints (i.e., maximum parts per million) are endogenous and embedded in the objective function, rather than entered as constraint constants.

Bid prices in terminal markets are taken as exogenous. This is unlike other formulations of spatial equilibrium problems, which treat demand quantities as fixed or (alternatively) specify demand functions for individual markets. Given the focus of our analysis (i.e., on grain quality attributes and buyer specifications) and limitations of available data, it was not possible to estimate demand schedules for the market segments (buyers) represented in our model. Fixed (bid) prices in terminal markets imply perfectly elastic demand, a reasonable assumption if the object is to model decisions by traders (grain buyers and sellers) in a competitive environment.

Formally, the objective is to maximize

$$Z = \sum_{i=1}^{7} [P_i - D_i^{\gamma} \cdot (1 - \beta_i)] NW_i - \sum_{j=1}^{9} \sum_{i=1}^{7} X_{ji} \cdot TX_{ji} \qquad (1)$$

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[12]Applications in the case of grain include Schrueben; Wilson and Preszler; and Johnson and Wilson (1993).

where P_i is the price bid ($/bu) by buyer i; D_i^v is a price discount[13] ($/bu) for vomitoxin; β_i is the probability that the contract limit for vomitoxin is satisfied; NW_i is the net weight of wheat shipments (mil. bu) to buyer i; X_{ji} is a shipment of wheat (mil. bu) from producing region j to buyer i; and TX_{ji} is the associated freight cost ($/bu). The bracketed term represents expected price for sales to buyer i.[14] Z is the expected net revenue from the sale of the crop.

Different contract limits and price discounts are specified for different buyers. In two cases, i.e., *Minneapolis feed* and *PNW Other,* no vomitoxin limit is specified, and the vomitoxin discount is zero. For sales to other buyers, expected revenue depends on the probability that the level of vomitoxin is less than a specified maximum. The larger is β_i, the lower is the probability that vomitoxin will exceed the contract limit, causing a discount to be applied (i.e., to be sold on a different contract).

Grain origins, indexed by j, are identified with North Dakota crop-reporting districts. Within each CRD, vomitoxin is treated as a random variable with known mean and variance. These parameters vary by CRD; hence, the probabilities of satisfying contract limits are influenced by the "weights" of different CRDs in grain shipped to terminal buyers.

Various quality measurements are based on weight net of dockage. Let N_{ji} denote the net weight of a shipment from region j to buyer i, defined

$$N_{ji} = X_{ji}(100 - DK_j)/100$$

(2)

where DK_j is the level of dockage (%) in region j wheat. Aggregating across producing regions, the total net weight of shipments to individual buyers is

$$NW_i = \sum_{j=1}^{9} N_{ji} \qquad (i=1,...,7)$$

(3)

Let w_{ji} denote the weight of region j in shipments to buyer i:

$$w_{ji} = N_{ji}/NW_i$$

(4)

The probability of satisfying an individual contract's vomitoxin constraint is based on the normal cdf:

$$\beta_i = \int_{-\infty}^{\delta_i} \frac{1}{(2\pi)^{1/2}} e^{-(1/2)u^2} \, du$$

(5)

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[13]The discount, D_i^v could represent the difference between P_i and the price in a secondary market. For example, if wheat is shipped to *Minneapolis Milling* but (at delivery) is found to have excess vomitoxin, it must be sold at the lower, *Terminal 6* ppm price.

[14]The expected price depends on β_i and is therefore endogenous.

where δ_i is given by

$$\delta_i = \frac{v_i - \sum_j \mu_j \cdot w_{ji}}{\sqrt{\sum_j w_{ji}^2 \cdot \sigma_j^2}} \quad . \tag{6}$$

The mean and variance of vomitoxin producing region j are denoted μ_j and σ_j^2, respectively, and v_i is the maximum allowed level of vomitoxin (without price discount).

Quality characteristics other than vomitoxin are treated as nonrandom. In practice, these are more easily measured and incorporated in contracts. Levels of protein or test weight are assigned to individual CRDs. All buyers, except in the feed markets, specify minimum levels of protein, test weight, vitreous kernels, and falling number. Maximum constraints apply to shrunken and broken kernels, foreign material, damage, and defects. Protein requirements vary across buyers.

$$\sum_j N_{ji} \cdot PRO_j / NW_i \geq KPRO_i$$

$$\tag{7}$$

where PRO_j is the protein level (%) in producing region j, and $KPRO_i$ is the minimum protein requirement (%) of buyer i. Constraints for other quality factors have the same general form.

Finally, supply constraints are imposed in each of the producing regions.

$$\sum_i X_{ji} \leq Q_j \qquad (j=1,...,9) \tag{8}$$

where Q_j is the total quantity (mil. bu) available for shipping from region j.

DATA SOURCES AND BASE-CASE PARAMETERS

This section describes data sources and explains how base-case parameters were derived. Most simulations use data from the 1993 crop year, which was characterized by a severe vomitoxin problem, particularly in eastern North Dakota. For comparison, an additional simulation was conducted using market conditions and quality distributions from 1994.

Quantity and Quality Availability. Mean values of quality characteristics were derived from data collected as part of the annual wheat quality survey by the Department of Cereal Chemistry and Technology, North Dakota State University. Samples were taken from each of the CRDs, and each wheat quality characteristic was measured. Wheat quantities produced in each CRD were taken from North Dakota Agricultural Statistics Service (1994-1995). These are the data shown in Tables 1 and 2. These CRDs accounted for 54% of total HRS production in the United States in 1993.

Transportation Costs. All shipments were assumed to move by rail, which is the predominant mode to each of these market destinations. Rail rates were those in effect during the fall of 1993 (Table 5) for 26 car movements.

Prices and Discounts.   Prices are not regularly reported or publicly disseminated for each of these markets and contracts. Thus, we constructed prices using a series of spreads for each of the grades/qualities used in our analysis. These were collected from several sources: interviews with traders, daily price reports from each of the Minneapolis Grain Exchange and Portland Grain Exchange, the USDA price reporting service at each market, and daily price sheets from a principal cash grain broker.

Table 5. Transportation Costs, $/bu

Producing Region	Destinations	
	PNW	Minneapolis
CRD 1	1.19	0.78
CRD 2	1.23	0.67
CRD 3	1.26	0.52
CRD 4	1.11	0.73
CRD 5	1.26	0.53
CRD 6	1.26	0.5
CRD 7	1.1	0.7
CRD 8	1.19	0.62
CRD 9	1.26	0.42

Price spreads were combined with Minneapolis futures prices at corresponding dates. For the 1993 crop year, the time period for these prices extended from August 1993 through April 1994. Prices for the 1994 crop year were from September to November 1994. A simple average was used in each case. As shown in Table 6, the discounts for Vomitoxin were more severe in 1993 than in 1994.

Quality Requirements.   Table 7 shows the quality requirements for the contracts included in our analysis. We made two simplifying assumptions about the treatment of PNW contracts. First, PNW Other was included to represent all importers off the PNW coast besides Korea and Japan. This contract was for No. 2, 14% protein, with no vomitoxin specification, and the price is generally reported by government price reporting services. Second, the Japan specification for vomitoxin was set at 0.5 ppm (maximum). Technically, that contract called for "scab-free," which is a proxy for vomitoxin-free. Because we lacked relevant supply data on scab, we specified a vomitoxin constraint for Japan with a limit of 0.5 ppm. Our treatment is somewhat more lenient than Japan's actual contract specification. However, given the presence of vomitoxin in all CRDs in 1993, a zero-vomitoxin specification would not have been feasible in model simulations.

SIMULATION RESULTS

The analytical model was used to identify the optimal solution and to evaluate effects of alternative procurement strategies. Base case results using data for 1993 are presented. We then examine the effect of both the mean level and standard deviation of vomitoxin on model results. For comparison, a simulation with data from 1994 (i.e., quality distributions and price spreads) is also presented. The remaining simulations focus on the effects of alternative procurement strategies by principal buyers. These entail adjustments in prices or changes in contract requirements.

Table 6. Base-case Prices and Vomitoxin Discounts

Market/Contract	1993		1994	
	Contract Price $/bu	Discount for Excess Vomitoxin $/bu	Contract Price $/bu	Discount for Excess Vomitoxin $/bu
Minneapolis				
Milling	5.36	.96 †	4.50	.25 †
Terminal, 2 ppm	5.05	.65 †	4.30	.05 †
Terminal, 6 ppm	4.4	1.59 ‡	4.25	1.20 ‡
Feed	2.81	n.a.	3.05	n.a.
PNW				
Korea	6.08	.51 *	5.00	.10 *
Japan	5.74	.17 *	4.90	0 *
Other	5.57	n.a.	4.90	n.a.

n.a. not applicable. † Alternative market: Minneapolis terminal, 6 ppm.
‡ Alternative market: Minneapolis feed. * Alternative market: PNW Other.

Each simulation reveals the impacts on the value of North Dakota wheat as reflected in the objective function, which measures expected sales revenue net of transportation costs. Shadow prices were derived to reflect the value of wheat in each CRD. These should be interpreted as values to traders at each origin, ignoring costs of assembly and blending (which are non-observable). Other variables of interest are the quantities shipped to individual markets, average levels of vomitoxin received, and probabilities of satisfying contract requirements.

Table 7. Contract Specifications

Contract	PRO % (Min)	TW lbs/bu (Min)	SB % (Max)	FM % (Max)	DAM % (Max)	DEF % (Max)	VIT % (Min)	FN (Min)	Vomitoxin ppm (Max)
Minneapolis									
Milling	14	58	3	.5	2	3	75	275	2
Terminal: 2 ppm	14	57	5	1	4	5	25	250	2
Terminal: 6 ppm	14	57	5	1	4	5	25	--	6
Feed	--	--	--	--	--	--	--	--	--
PNW									
Korea	14.5	58	3	.5	2	3	25	350	2
Japan	14	57	5	1	2	5	25	300	.5
Other	14	57	5	1	4	5	25	--	6

-- not specified.

A measure of risk was developed to compare alternative contracts from a trader's perspective. Let EP_i denote the expected price for sales to buyer i. This is the bracketed term in (1), a function of the vomitoxin discount D_i^v and probability of acceptance β_i. Equivalently, EP_i can be expressed as

$$EP_i = \beta_i \cdot P_i + (1-\beta_i) \cdot S_i \tag{8}$$

where $(1-\beta_i)$ is the probability of rejection and S_i is the price in a secondary contract with looser vomitoxin specifications.[15] The standard deviation of price is defined as

$$\sigma_i = [\beta_i(P_i - EP_i)^2 + (1-\beta_i)(S_i - EP_i)^2]^{1/2} \tag{9}$$

and the coefficient of variation is

$$CV_i = \frac{\sigma_i}{EP_i} \tag{10}$$

Following Barry et al. (pp. 320-21), we use CV_i as a measure of risk, in this case, risk borne by the seller when shipping to buyer i. Risk increases with the vomitoxin discount and decreases with the probability of acceptance.

Base Case Results. Tables 8 and 9 show selected base case results, with comparisons to other scenarios. The objective function value, $1.216 billion, is interpreted as expected value of the state's HRS crop if optimally blended and shipped. Base-case flows are summarized in Figure 1. Flows are to the *domestic milling* market and to *PNW Korea* and *PNW Other*. There are no flows to Japan or other Minneapolis markets.[16] The pattern of flows (by CRD) also differs drastically from what might be expected based on transportation cots. For example, *Domestic Milling* receives most of its wheat from western CRDs, while part of the Korean contract is supplied by eastern CRDs. This is due to the combined effects of quality availability, quality requirements, price spreads, and discounts for vomitoxin in different contracts. Flows to *PNW Other* are due to a relatively high price and no vomitoxin specification.

For the 3 contracts receiving grain, the quality constraints for vitreous kernels, falling number, damage, and defects are not binding. Protein is binding for *Domestic Milling* and *PNW Korea*, while test weight is binding for *PNW Other*.

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[15]Recall that D_i^v is the difference between prices in "primary" and "secondary" markets. Thus,

$$EP_i = \beta_i \cdot P_i + (1-\beta_i) \cdot S_i = \beta_i \cdot P_i + (1-\beta_i) \cdot P_i - (1-\beta_i) \cdot P_i + (1-\beta_i) \cdot S_i$$

$$= P_i - (1-\beta_i) \cdot (P_i - S_i) = P_i - (1-\beta_i) \cdot D_i^v$$

[16]For reference, exports of HRS off the PNW during 1993/94 were Japan 45 million bushels; Korea 12 million; and Total PNW 154 million.

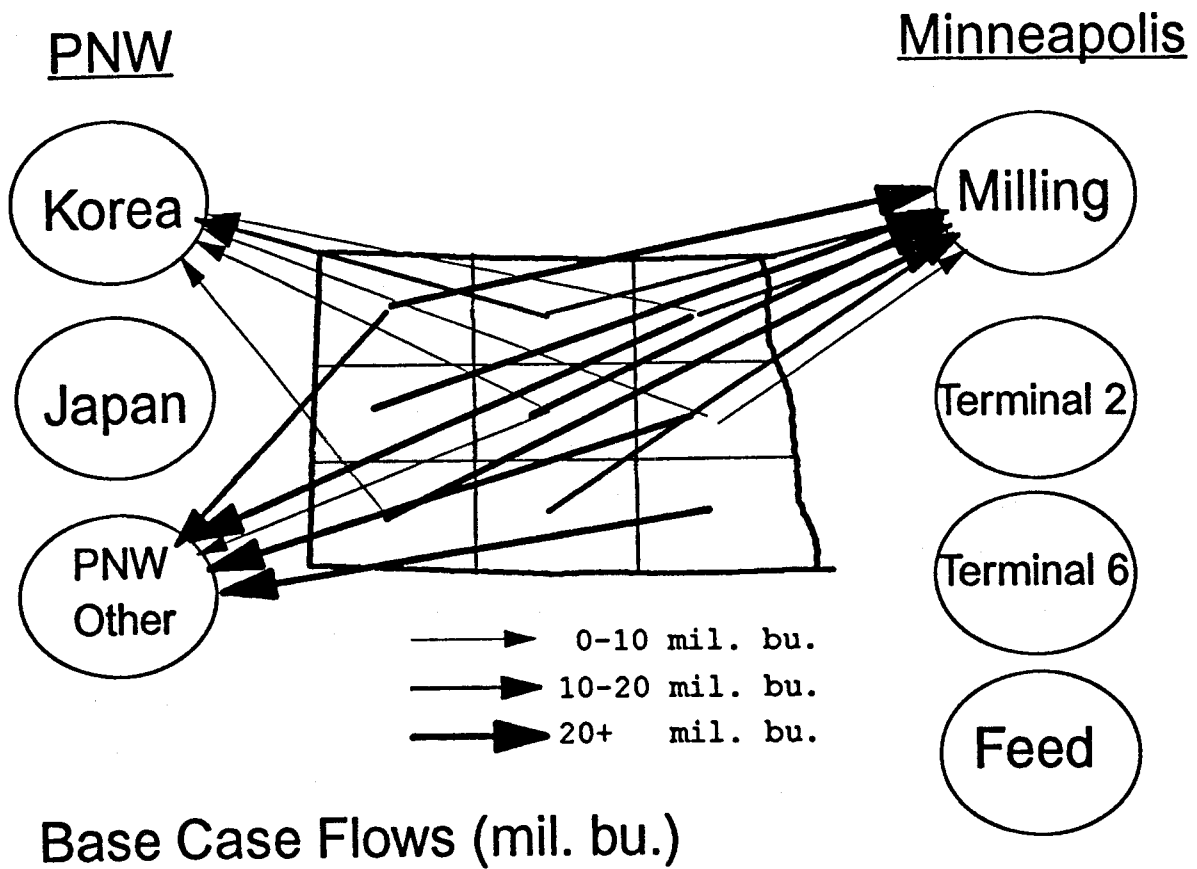Figure 1. Base Case Flows (mil. bu.)

Table 8. Selected Results From Model Simulations

Simulation	Objective Function ($ mil)	Quantity (mil. bu.)			Expected Value Vomitoxin			Probability of Satisfying Requirements		Traders' Risk (CV)	
			PNW			PNW					
		Milling	Korea	Other	Milling	Korea	Other	Milling	Korea	Milling	Korea
Base Case	1216	139	20	111	1.12	1.27	5.21	.97	.91	.033	.024
Normal Year (No Vomitoxin, Normal Price Spreads) *	1302	53	68	0	0	0	0	1	1	0	0
1994 *	952	71	0	157	1.55	n/a	n/a	.70	n/a	.026	n/a
CRD5 Vom. Mean=0	1233	139	39	91	1.22	1.26	5.40	.98	.92	.023	.023
CRD5 Vom.Variance=0	1228	132	34	103	1.35	1.26	5.22	.99	.92	.021	.023
Domestic Milling Vom. Discount=0	1249	151	48	69	2	1.28	5.66	.5	.93	.098	.022
Damage 2% Max for PNW Other*	1163	0	68	156	1.34	1.57	2.98	.93	.76	.047	.037

*Some flows are omitted from table.
n/a not applicable.

Expected levels of vomitoxin and probabilities of satisfying constraints are also shown in Table 8. For *Domestic Milling* and *PNW Korea*, expected levels are well below contract limits (2 ppm). The vomitoxin level for *PNW Other* is relatively high, at 5.21 ppm; no vomitoxin limit is specified for that contract, which functions as the secondary contract for shipments to Korea and Japan.

Probabilities of satisfying vomitoxin constraints vary across contracts. These probabilities are determined by the model and should be interpreted as optimal from a seller's perspective, given relevant price relationships and the spatial distribution of quality. In the case of *Domestic Milling*, the probability of satisfying the requirement (2 ppm) is .97. This indicates that it is optimal for traders to ship wheat to *Domestic Milling* with a .03 probability of not satisfying contracts requirements.

The standard deviation of vomitoxin in shipments under the *Domestic Milling* and *PNW Korea* contracts are .18 and .51, respectively. This indicates greater uncertainty about vomitoxin levels in shipments to the *PNW Korea* contract. From a seller's perspective, the coefficient of variation (for expected returns) provides a more meaningful way to compare relative risks. As shown in Table 8, the CV_i for *Domestic Milling* is somewhat higher than that for *PNW Korea* in the base case. This is largely due to the difference in vomitoxin discounts, 96 c/b for *Domestic Milling* versus 51 c/b for *PNW Korea*. Given the higher penalty for rejection, the *Domestic Milling* contract poses a greater risk. This induces a greater precaution by traders (lower mean level of vomitoxin) in assembling grain for delivery to domestic millers.

Shadow prices were derived for each CRD and are shown in Table 9. These are interpreted as the value of an additional bushel in each CRD, given mean quality characteristics. The results mirror the wide disparity in prices actually observed during 1993. The value of an additional bushel in regions with a high level of vomitoxin (e.g., CRD 3, 6, and 9) is substantially lower than in contiguous regions, with discounts above what would be expected based on transport costs. Regions with low levels of vomitoxin (and otherwise better quality) experience higher prices (e.g., CRD 2, 4, 7, and 8).

Normal Crop Year Results. To provide a perspective on what may occur in a more normal year we revised the model parameters. The term "more normal" is somewhat elusive, but two changes seemed in order. Vomitoxin was eliminated in each region, and "more normal" price relationships were assumed in the Minneapolis and PNW markets, removing the (approximate) impact of vomitoxin on price spreads.

One of the peculiar features of the 1993 crop year was the abnormally wide price spreads between geographic markets and between buyers in the same market (i.e., Minneapolis or PNW). To evaluate this impact, the model was run using price and basis levels more typical of these markets.

Spreads and basis values were taken from the same time interval in 1992/93.[17] Vomitoxin levels (and variances) were reduced to zero in each CRD, but base case values were retained for other quality parameters.

Flows under this scenario are shown in Figure 2. Notable differences are the drastic reductions in flows to *Domestic Milling* and *PNW Other*, which are offset by increases to *Minneapolis Terminal*, *PNW Korea*, and *PNW Japan*. These would be more representative of a normal year. *PNW Korea* is the premium market. Protein constraints are binding for the *Domestic Milling, PNW Korea, and PNW Japan* contracts. The overall poor quality of wheat, including high damage due to the unusually cold, wet growing conditions of 1993, constrains flows in all markets. The probability of satisfying requirements increases to 1 and risk decreases to nil (Table 8), reflecting the assumption of zero vomitoxin.
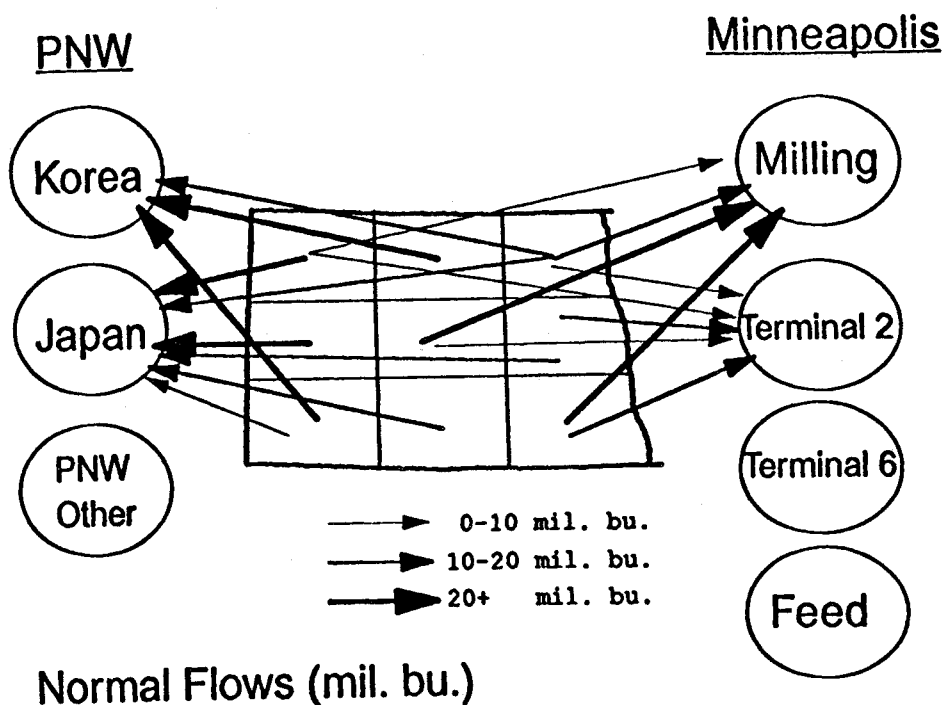

Normal Flows (mil. bu.)

Figure 2. Normal Flows (mil. bu.)

[17]Contract prices were as follows: *Domestic milling* 5.35; *Terminal* 5.25; *Minneapolis feed* 2.81; *PNW Korea* 6.29; *PNW Japan* 5.95; *PNW Other* 5.85.

Table 9. Shadow Prices for Individual CRDs

CRD*	Base Case	Normal Year, No Vom., Normal Price Spreads	CRD5 Vomitoxin mean=0	var.=0	Zero Vom. Discount for Milling	Damage 2% Max for PNW Other
1	449	455	438	439	475	510
4	474	484	468	468	485	510
7	475	480	471	472	474	492
2	489	531	490	489	487	530
5	431	476	494	478	486	467
8	469	472	465	463	482	487
3	411	461	417	417	426	313
6	412	453	415	415	391	254
9	423	475	421	421	429	365

*Crop reporting districts are arrayed as a 3x3 grid. The three western districts (from north to south are 1, 4, and 7. Central districts are 2, 5, and 8. Eastern districts are 3, 6, and 9.

The objective function value increases by $86 million which could be interpreted as the impact of vomitoxin on the value of the wheat crop. This may appear low compared to other estimates, but the difference can be explained by several qualifications. One is that the analysis does not capture anyyield effects, a notable concurrent problem with the incidence of vomitoxin. Second, this analysis allows wheat to be shipped to other markets and sold under alternative contracts which would have the effect of mitigating some of the effects of discounts.

Shadow prices for individual CRDs are shown in Table 9. The premium in CRD2 reflects high quality and protein and the proximity to *PNW Korea*. The low value in CRD1 reflects a low average protein level, 13 percent. Low values in CRDs 3 and 6 are likely due to high damage.

Results for 1994 Crop Year. For comparison, simulations were conducted with 1994 crop quality data and market prices. As shown in Table 2, vomitoxin was also a significant problem in the eastern producing regions, particularly CRD3 and CRD6. Western CRDs (1, 4, and 7) had virtually no vomitoxin in 1994.[18] Average protein levels were higher in regions with high vomitoxin, a fact that helps to explain the flow patterns in model simulations.

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[18]In the 1994 crop year vomitoxin tests were not conducted in CRDs 1, 4, and 7 as part of the wheat quality survey. Hence we assumed that sample means and variances were zero. Sample means in CRDs 2, 5, and 8 were based on composite samples. In this case sample variances for these CRDs were not available for 1994. For simulation purposes, we predicted the standard deviations for CRDs 2, 5, and 8 from a regression model with vomitoxin sample means from 1993 and 1994 as the explanatory variable and sample variances as the independent variable.

Selected results are shown in Table 8 and flows in Figure 3. The objective function is $0.951 billion, lower than the base case due to substantially lower prices. Optimal flows are to *PNW Other* (157 million bu), *Domestic Milling* (70 million bu), and the Minneapolis *feed* market (44 million bu). The expected vomitoxin level for *Domestic Milling* is higher than in the base case, and the probability of satisfying requirements is lower. In large part, that is due to the coincidence of high Vomitoxin and high protein in CRDs 3, 6, and 9. Other CRDs did not have sufficiently high protein levels to satisfy contract specifications, which are binding for both *Domestic Milling* and *PNW Other*. This forced high-vomitoxin grain into the solution for these contracts. The results also demonstrate that trader's risk is lower in shipping to the *Domestic Milling* contract.

Effects of Means and Variability in Vomitoxin on Prices. Both the mean and variance of vomitoxin affect regional wheat prices as well as spatial flows. Higher mean values for vomitoxin affect blending opportunities, just as they do for other quality characteristics. Higher variances can increase the likelihood that wheat shipments would be rejected by buyers.

To evaluate the relative effects of changes in the mean and variance of vomitoxin on wheat prices, simulations were conducted with different distributions for vomitoxin in one particular region. CRD5 was chosen for demonstration purposes; it is centrally located and not extreme in terms of its vomitoxin distribution. The mean level and variance of vomitoxin in this region were iterated within ranges observed in other regions. Results are summarized in terms of the impacts on shadow price for CRD5.
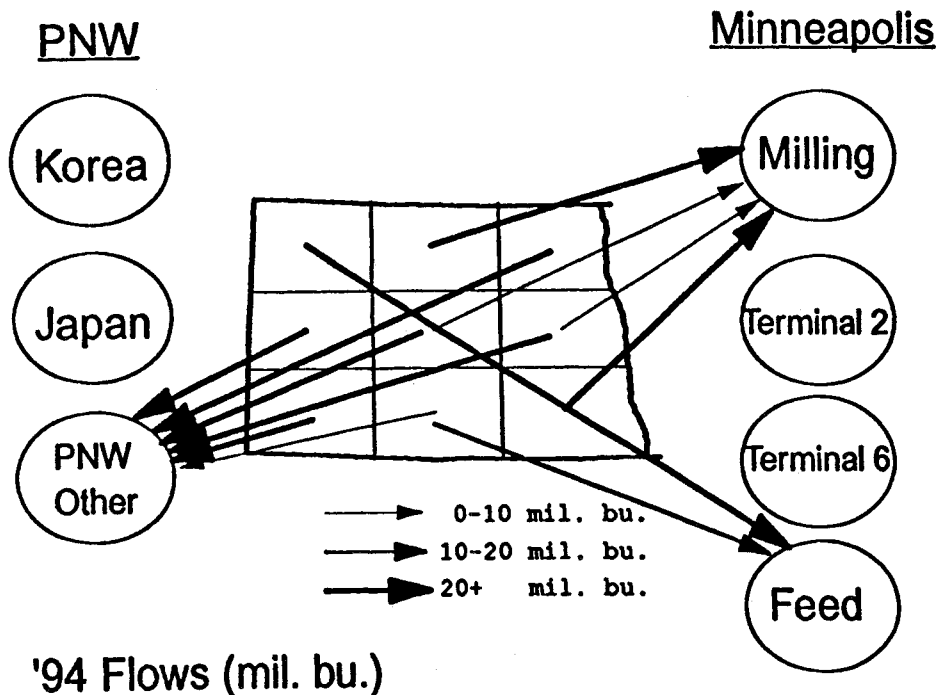

Figure 3. '94 Flows (mil. bu.)

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Mean Level. Lower mean levels of vomitoxin increase the value of wheat (Figure 4). There is a large reduction in the shadow price when vomitoxin increases from 0.3 to 1.2 ppm; thereafter, the impact on price diminishes. An increase in vomitoxin from 0.1 to 1.0 ppm decreases price by 13c/b, while an increase from 1.0 to 2.0 ppm decreases price by 4c/b.

Comparisons to the base case are made in Table 7. The effect on flows of reducing the mean vomitoxin level for CRD5 to zero is shown. The objective function increases to $1.233 billion. The added value reflects a larger flow to *PNW Korea* (19 mil. bu. more than in the base case). This affects *PNW Other,* which receives 19 million bu. less than in the base case and with more vomitoxin.

The optimal probability of satisfying requirements increases slightly relative to the base case. Twice the level of wheat is supplied; however, *PNW Korea* receives the same expected level of vomitoxin with the same probability of satisfying requirements. Traders' risk does not change for the *PNW Korea* market. Elimination of vomitoxin in CRD5 allowed more grain to be shipped to the highest priced market. CRD5 switches and fully supplies *Domestic Milling,* freeing up CRDs 2 and 7 to supply *PNW Korea.* As a result, the trader's risk in the *Domestic Milling* contract decreases.

Standard Deviation. The standard deviation also has a negative effect on the value of wheat in CRD5 (Figure 4). The effects of successive increases in the standard duration are fairly constant until it exceeds 3.0; thereafter, the shadow price stabilizes. The logic is that, with increases in the higher standard deviation for vomitoxin, grain from CRD5 presents greater risk to traders. In particular, there is a higher probability of rejection in higher-valued markets. Conversely, when the standard deviation for CRD5 is reduced to zero, the objective function value increases (Table 8) to $1.22 billion. This implies that crop value would increase if there were no uncertainty about the vomitoxin level or if the variability were reduced to nil.
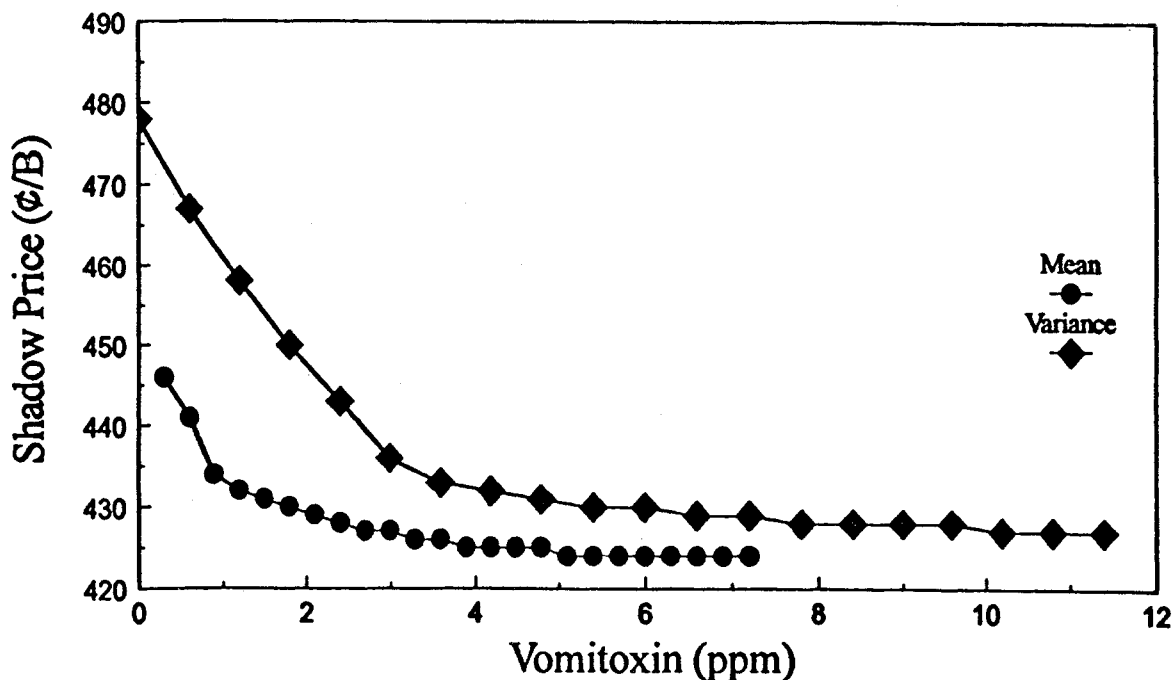

Figure 4. Impact of CRD5 Vomitoxin Distribution on Shadow Price (CRD5)

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Changes in flows to individual markets are also interesting. With zero standard deviation for vomitoxin in CRD5, more grain is shipped to *PNW Korea*, the higher priced market. The probability of satisfying requirements and coefficient of variation for the *PNW Korea* contract are about the same as in the base case; more grain is shipped with little change in risk. In the case of *Domestic Milling*, shipment volumes are reduced (slightly) relative to the base case, but the coefficient of variation is substantially lower.

In both of these cases, the marginal value of wheat in CRD5 increases relative to the base case (Table 9). A zero mean for vomitoxin increases the CRD5 shadow price by $0.63, while zero uncertainty (standard deviation) increases it by $0.47. These values indicate the premiums that would have occurred if there had been no vomitoxin in CRD5 or if traders had perfect information about the true level of vomitoxin in purchased grain. Shadow prices for other regions are also affected by the level and standard deviation of vomitoxin in CRD5. This reflects changes in blending opportunities across producing regions and changes in aggregate grain flows. The effects are not uniform: shadow prices rise in some CRDs (e.g., 3 and 6) and fall in others (1, 4, 7, and 8) when vomitoxin in CRD5 is eliminated.

These results demonstrate how the value of wheat is affected by both the mean and variance of quality characteristics. Changes in either can affect the distribution of flows, prospective risks and returns from shipping to different markets.

Domestic Milling Strategies Toward Vomitoxin. There are two important strategic aspects to procurement. One is the buyer's bid price, including (explicit or implicit) discounts for undesirable characteristics. The other is the contract requirement, or specification. In the case of the *Domestic Milling* market, selection of contract requirements for vomitoxin is somewhat constrained, due to the interpretation of FDA regulations. Thus, pricing decisions and discount values for vomitoxin are critical for this market segment. Changes in millers' bids and discounts affect the entire system. However, here we focus on three variables: the expected value of vomitoxin in shipments to *Domestic Milling*, the probability of satisfying requirements, and aggregate flows.

Discounting for Vomitoxin: These effects were evaluated by changing the discount for excess vomitoxin in the *Domestic Milling* market.[19] As expected, the value of the objective function rises as the discount is reduced (Figure 5). With no milling discounts for vomitoxin ($D_i^v=0$), the objective function reaches a value of $1.249 billion (Table 8).

The volume shipped to *Domestic Milling* is inversely related to the discount. At low discount levels, *Domestic Milling* attracts larger flows from regions with higher vomitoxin levels. As the milling discount increases, more is shipped to *PNW Other;* curiously, flows to *PNW Korea* decline due to changing availabilities of high-quality wheat (Figure 6).

The expected level of vomitoxin received by *Domestic Milling* is inversely related to the vomitoxin discount (Figure 7). With zero discount, the mean level is 2.0 ppm, the constrained value. The probability of satisfying contract requirements decreases sharply and traders' risk increases. The mean value decreases rapidly until the discount reaches $1.00; thereafter, it changes little. These

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[19]For this set of simulations only, we vary the discount without changing any contract prices. In other words, D_i^v becomes an explicit discount for *Domestic Milling,* no longer simply the price spread between *Domestic Milling* and *Terminal 6*.
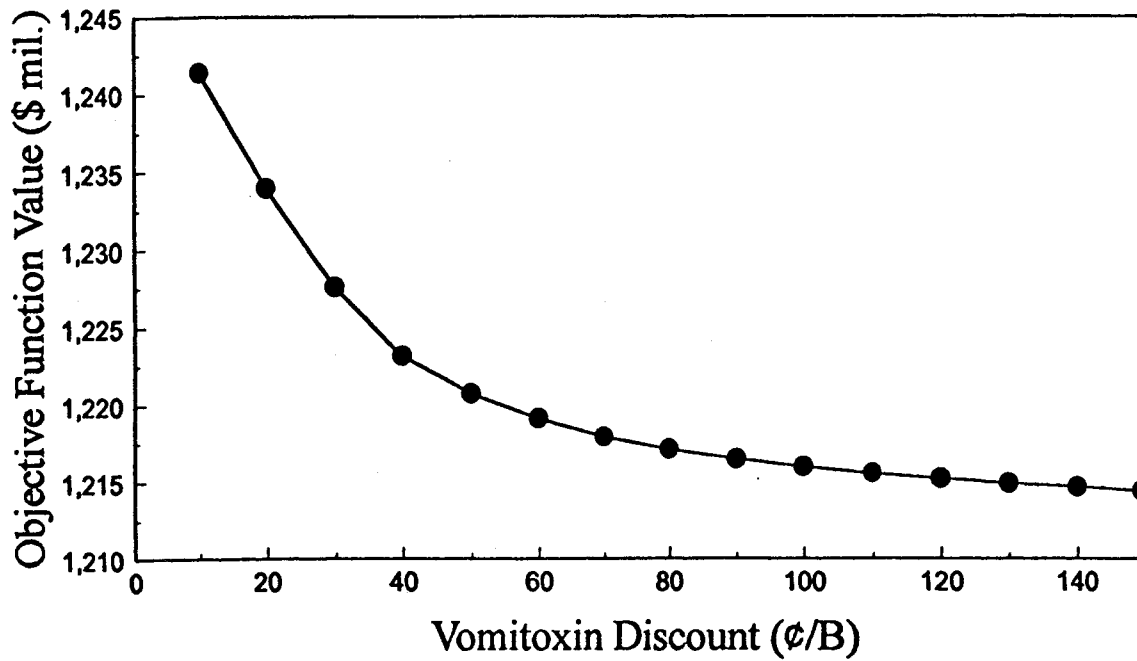
Figure 5. Impact of Domestic Miller's Vomitoxin Discount on Objective Function
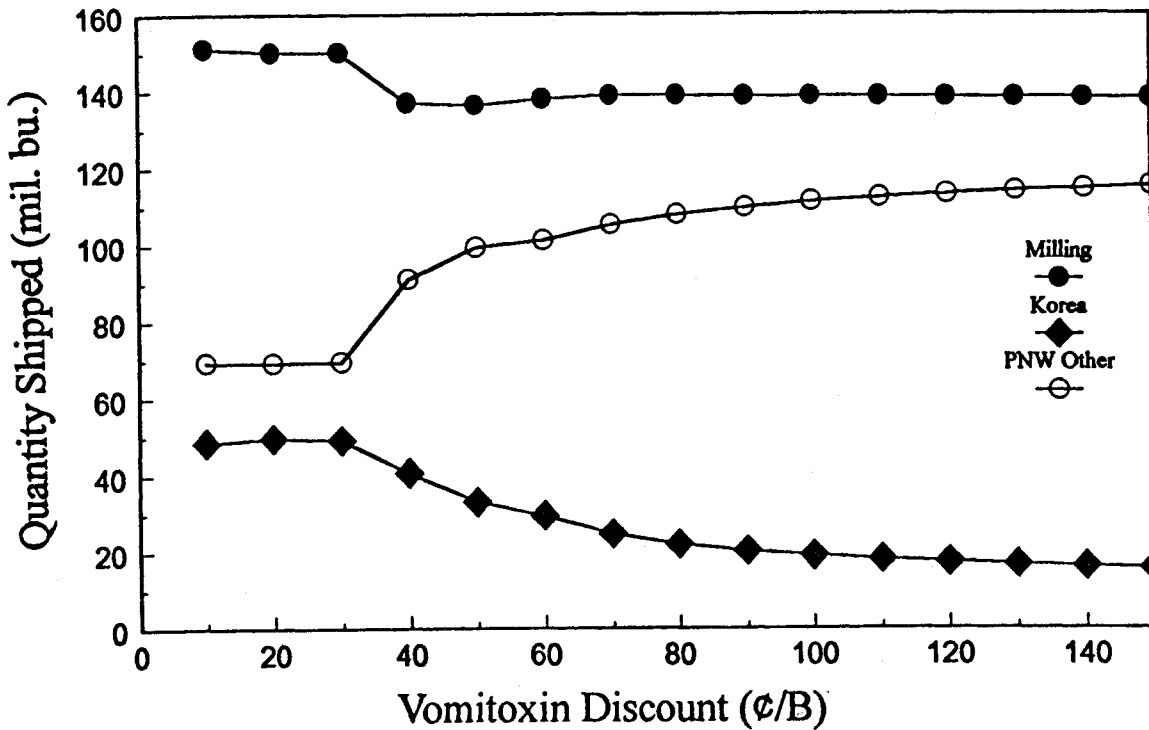

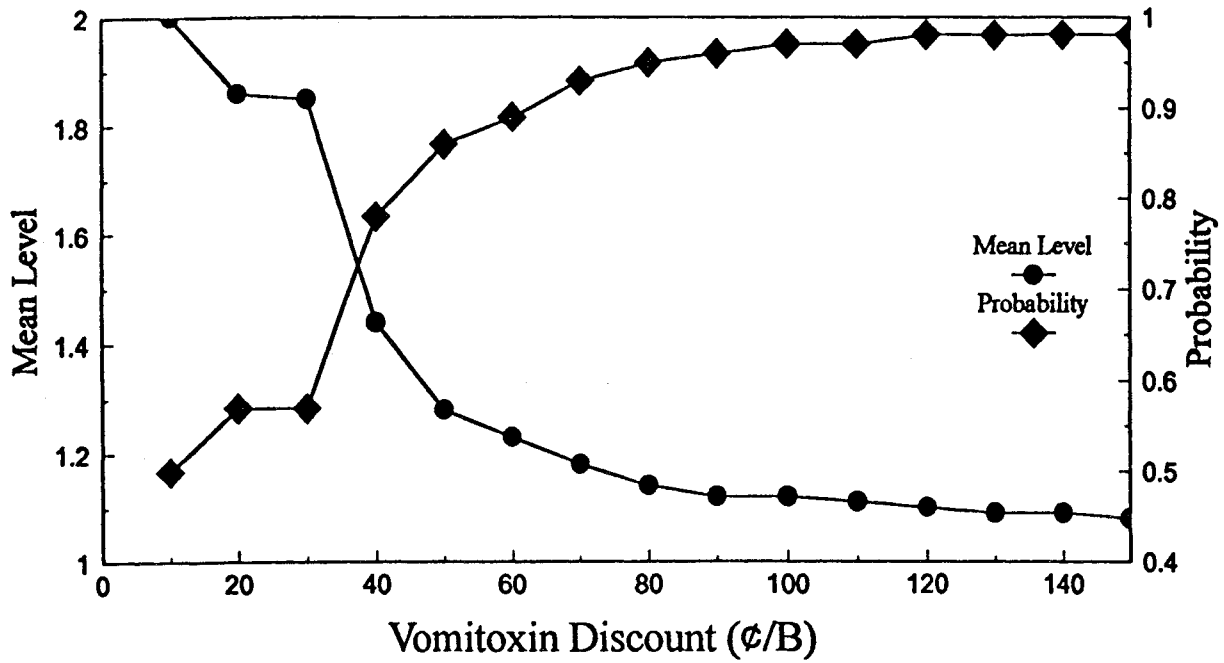Figure 6. Impact of Domestic Miller's Vomitoxin Discount on Flows

Figure 7. Impacts of Domestic Miller's Vomitoxin Discount on Vomitoxin Level and Probability of Satisfying Contract Requirement
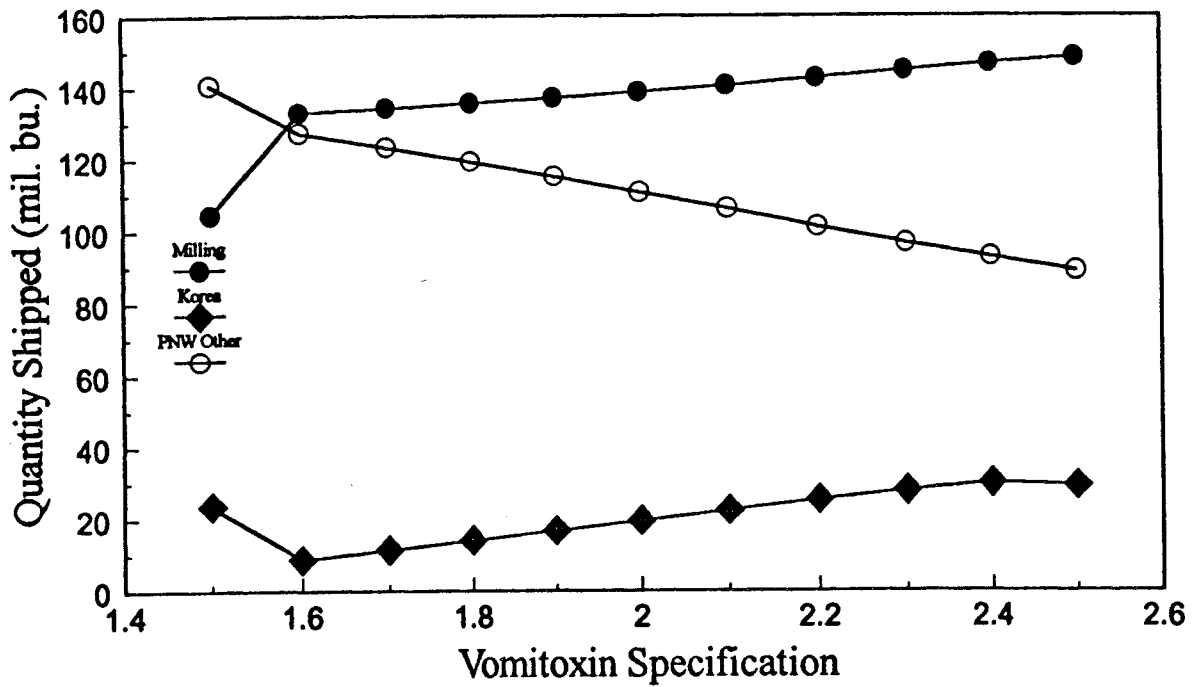

Figure 8. Impact of Domestic Miller's Vomitoxin Specification on Flows

results show that discounts are a critical variable affecting competition between markets and contracts. With higher discounts, flows to the *Domestic Milling* market are reduced. However, the grain shipped is of higher quality, with a greater probability of conforming to requirements.

Domestic Vomitoxin Specifications: An alternative to changing the discount is to adjust the vomitoxin specification. To evaluate these effects, the vomitoxin specification for *Domestic Milling* was iterated between 1.5 and 2.5 ppm. Quantities shipped to *Domestic Milling* decline as the specification is tightened and increase as the specification is relaxed. (Figure 8.)

By tightening the specification, *Domestic Milling* receives a lower expected level of vomitoxin. For the entire range of vomitoxin limits (1.5 to 2.5 ppm), the expected value of vomitoxin is always less than the specified maximum. In effect, the discount for excess vomitoxin causes traders to err on the side of caution, shipping lower mean levels of vomitoxin than allowed under the specification. At 1.5 ppm, the expected level of vomitoxin is 0.82, with a probability of satisfying the requirements of 98%, marginally higher than in the base case (Figure 9).
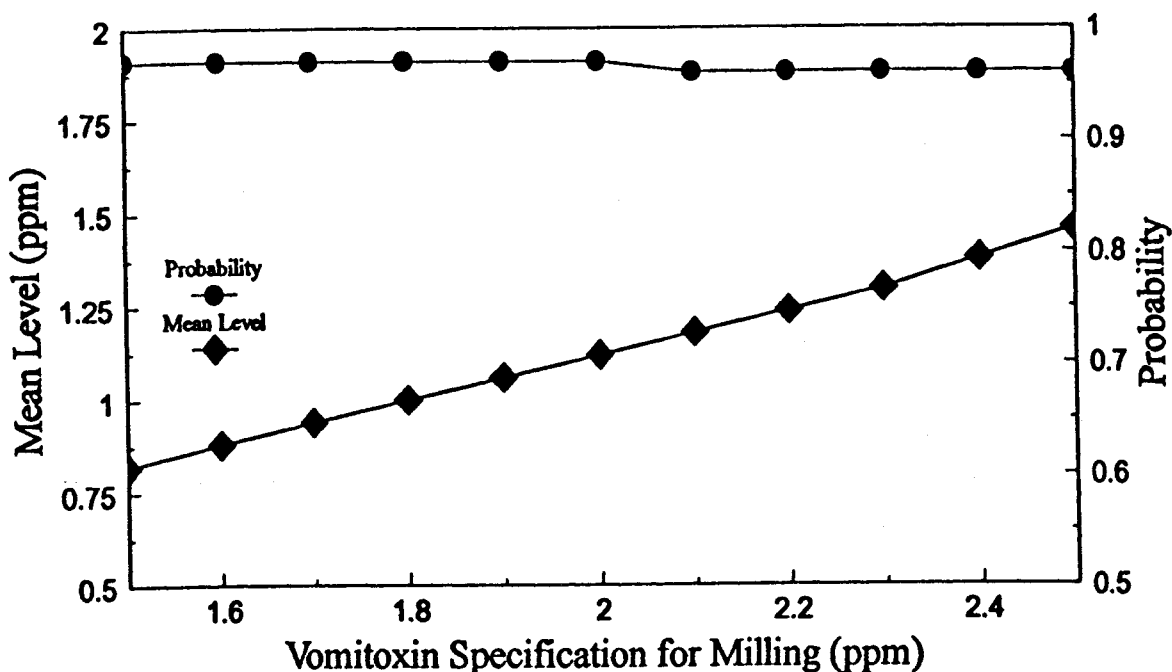

Figure 9. Impacts of Miller's Vomitoxin Specification on Vomitoxin Level and Probability of Satisfying Contract Requirement

Analysis of Importer Strategies. In some cases, importers have more latitude than domestic buyers in their choice of specifications and pricing strategy. The base case includes drastically different prices and contract terms for different buyers. This reflects an important dimension of buyer competition: in spatially and quality differentiated markets, importers compete against each other and domestic buyers through price and contract specifications.

Analyses were conducted on these aspects of competition in the PNW export market. Simulations were conducted using *PNW Japan* as an example (though equally interesting results could be shown with other importers). *PNW Japan* receives no wheat in the base case, either because it offers too low a price or because its specification is too restrictive. The following simulations consider both possibilities. To simplify the analysis, and to demonstrate more clearly the competition between PNW and Minneapolis, we exclude *PNW Korea* from these simulations (by setting its price to zero).

Price Increase: To attract grain to *PNW Japan* without changes in specifications, the price must be raised to $6.04/b, 30 cents higher than assumed in the base case. Figure 10 shows the effects of successive price increases on quantities shipped to different buyers. Price increases allow *PNW Japan* to bid wheat away from *Domestic Milling*. Quantities received by *PNW Other* show a moderate increase, for reasons having to do with changes in availabilities and blending opportunities.

Figure 11 shows the mean level of vomitoxin shipped to *PNW Japan* and the probability of satisfying requirements for a range of contract prices. Vomitoxin levels increase with the contract price, and probabilities decrease moderately. A higher premium for *PNW Japan* over other contract alternatives induces larger total shipments and expanded sourcing from particular regions, with some reduction in average quality received. However, the mean vomitoxin level remains well below the specified maximum, 0.5 ppm.

Vomitoxin Specification: From a buyer's perspective, an alternative to changing the price is to change the contract specification. In the present context, that means relaxing the allowable maximum for vomitoxin shipped to *PNW Japan*. Figure 12 shows the effect of different contract limits on aggregate flows, assuming a fixed contract price for *PNW Japan* ($6/bu). As the allowable maximum increases from 0.5 to 0.9 ppm, *PNW Japan* is able to bid wheat away from *Domestic Milling* just as it did by raising prices. This reinforces the point that quality specifications affect spatial flows.

Figure 13 shows how relaxing Japan's vomitoxin specification affects qualities received. As the allowable maximum rises, so does the mean level of vomitoxin in shipments to *PNW Japan*. Probabilities of acceptance also increase due to relaxation of the vomitoxin constraint.

Efficacy of Stringent Damage Specifications to Reduce Vomitoxin. One strategy pursued by grain buyers is to use contract specifications for easily measured quality factors as proxies for other, less easily measured characteristics. By tightening contract limits for the easily measured factor, the buyer can control (indirectly) expected levels of other factors. Some buyers use damage specifications to control the expected level of vomitoxin, which is rarely measured at country elevators. The efficiency of this depends on the correlation between these two variables ($r = 0.79$ in 1993).

To evaluate these effects, the base model was run with varying levels of damage allowed for *PNW Other*, a contract without a vomitoxin limit. Starting from the base-case limit of 4%, the allowable maximum was reduced incrementally to 2%. Results demonstrate that the expected level of vomitoxin decreases with tighter specifications on damage (Figure 14). This confirms that the expected vomitoxin level can be controlled through tighter specifications on other, more easily measured characteristics (damage in this case). However, this method of control is not perfect; with 2% damage allowed, expected vomitoxin for the contract is still relatively high at 3 ppm.
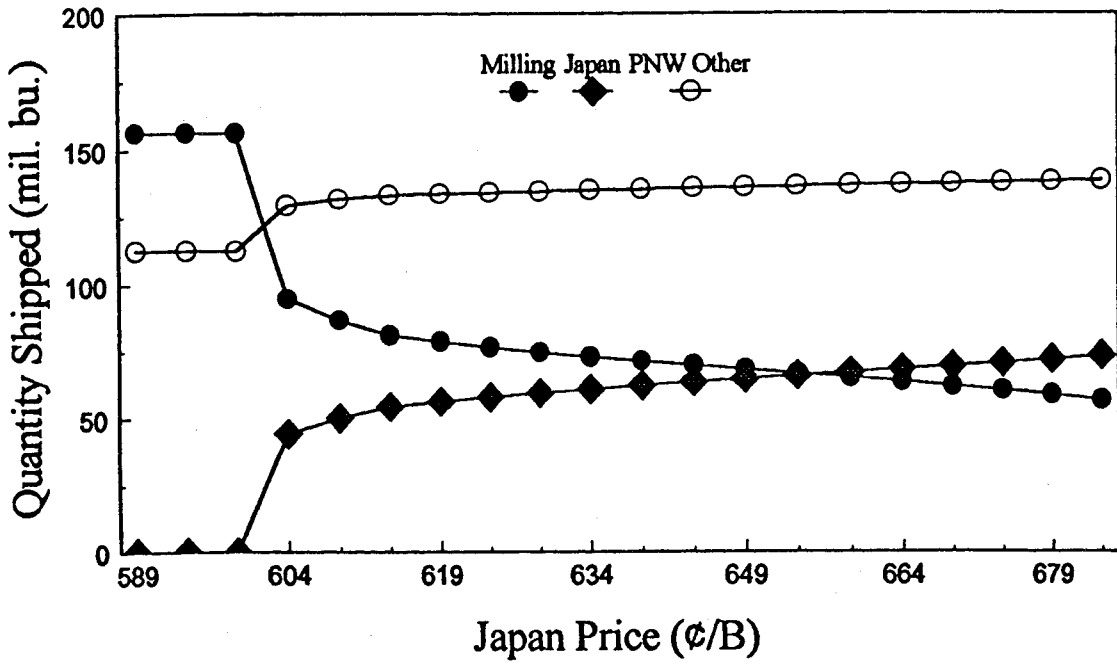
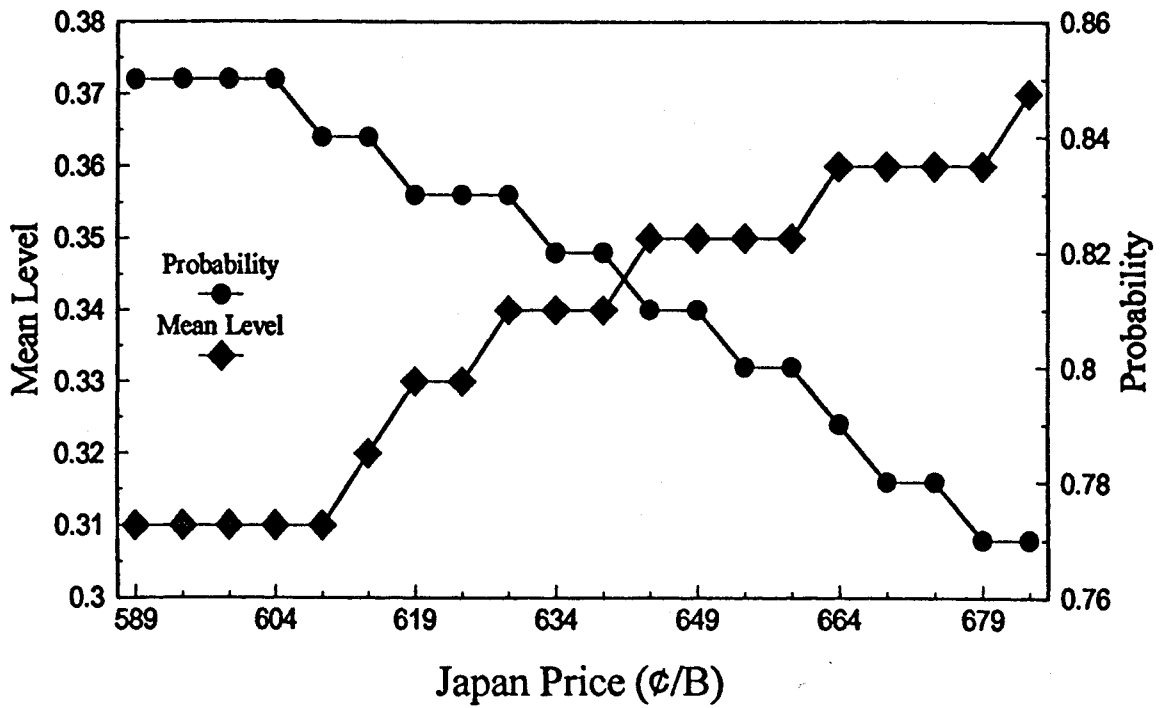Figure 10. Impact of Japan's Price on Flows

Figure 11. Impacts of Japan's Price on Vomitoxin Level and Probability
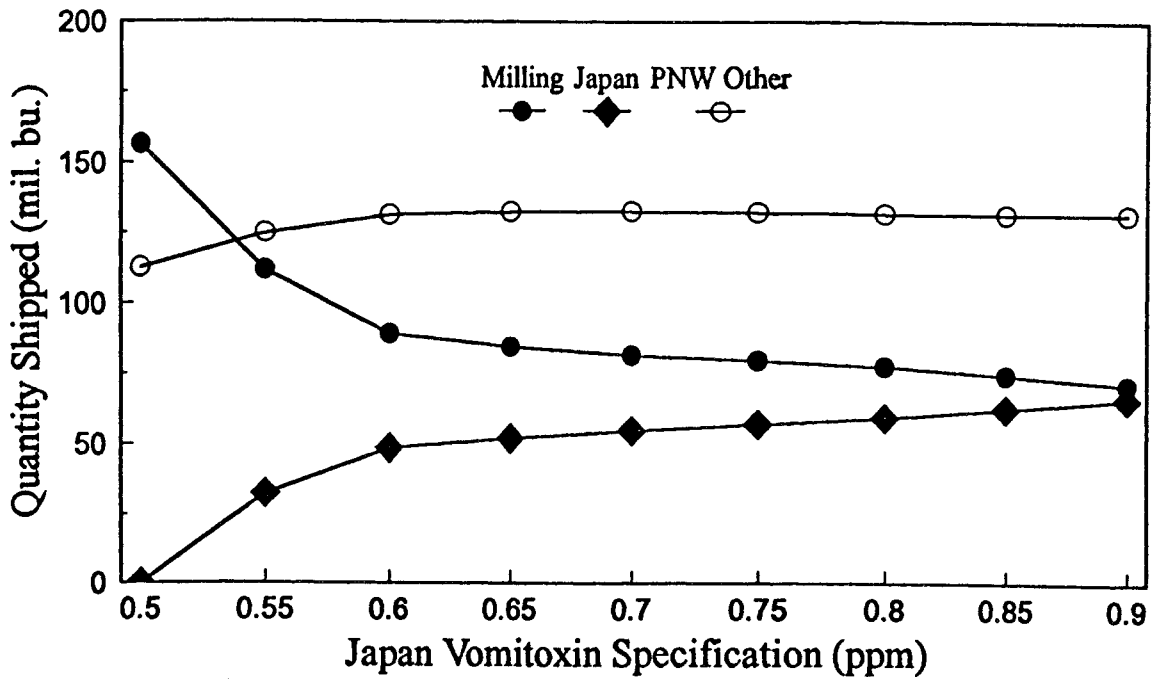of Satisfying Contract Requirement

30

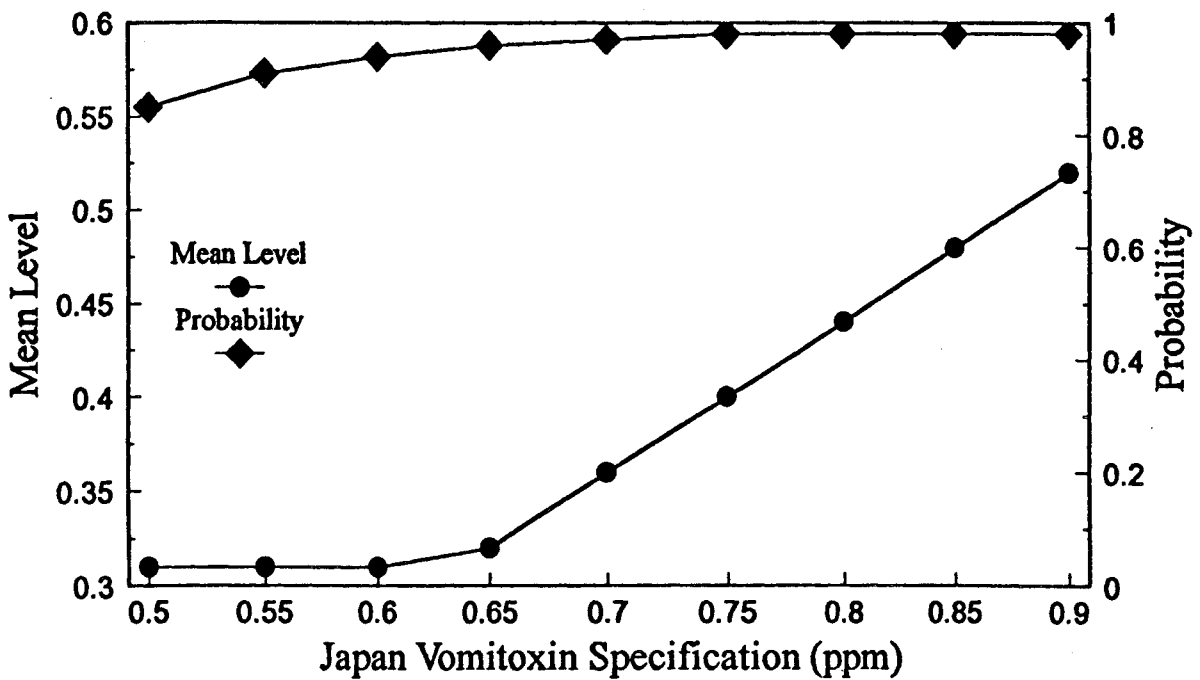Figure 12. Impacts of Japan's Vomitoxin Specification on Flows

Figure 13. Impacts of Japan's Vomitoxin Specification on Vomitoxin Level and Probability of Satisfying Contract Requirement
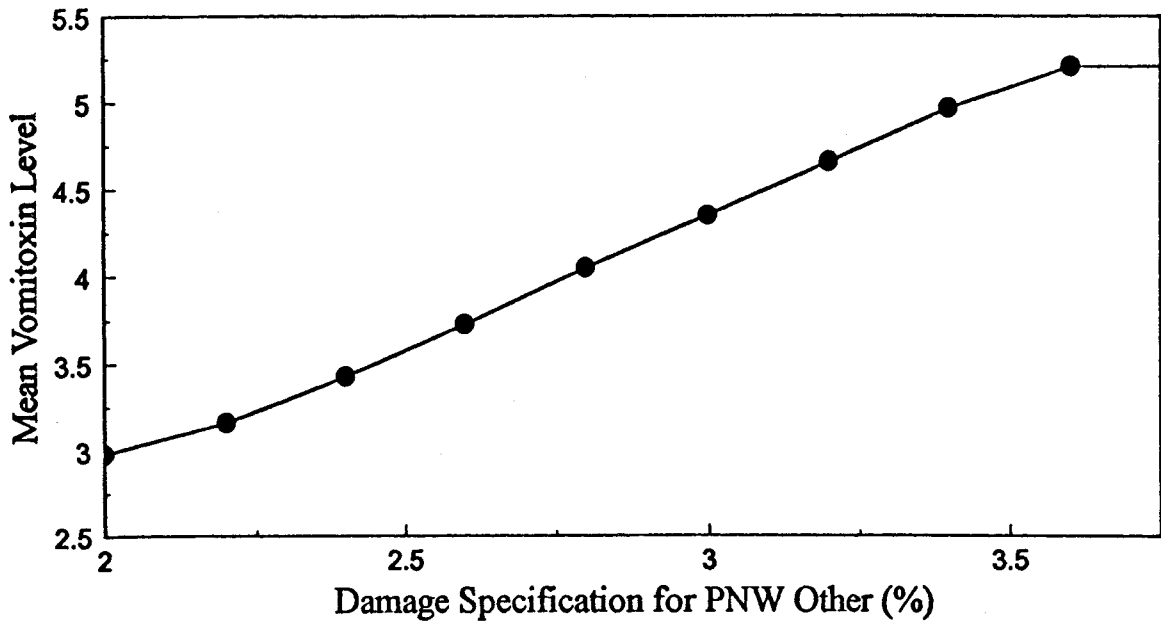
Figure 14. Impact of PNW Other Damage Specification on Vomitoxin Level
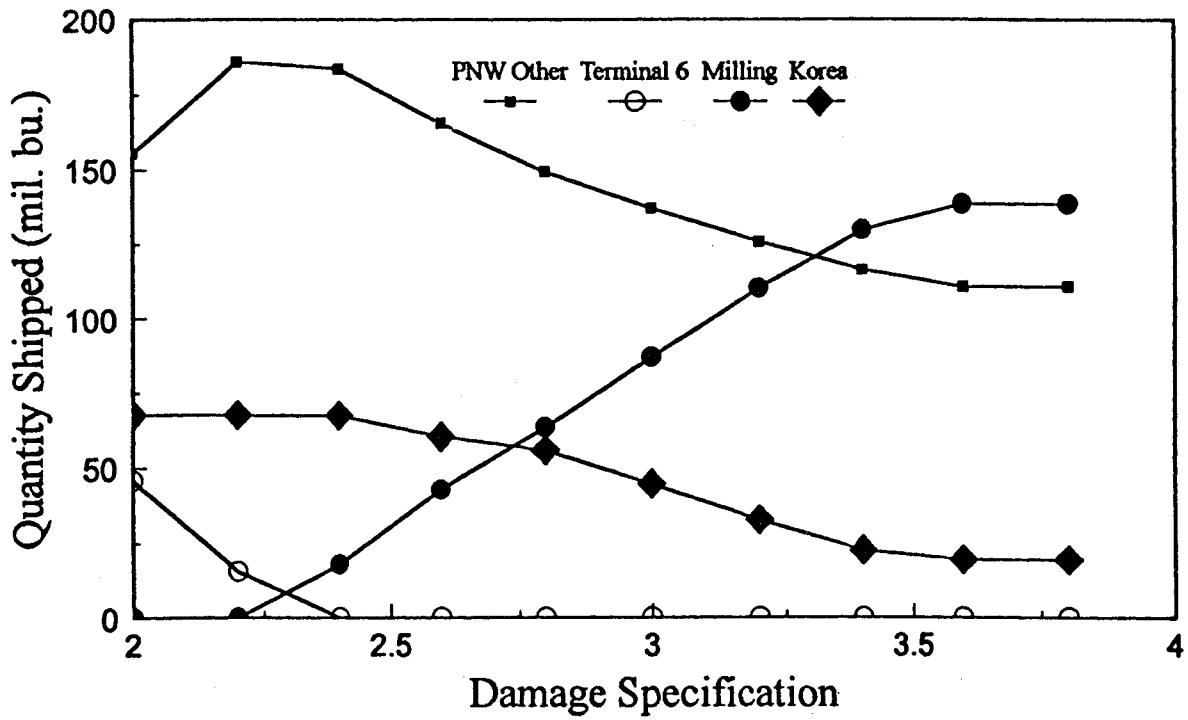

Figure 15. Response of Supply to PNW Other Damage Specifications

More interesting are the changes in aggregate flows (Figure 15). As *PNW Other* tightens its damage specification, larger flows are attracted to this contract, and volumes shipped to premium markets, *Domestic Milling*, are reduced. This is a counterintuitive result, in sharp contrast to that described for Japan in the preceding section (where relaxation of the vomitoxin constraint induced largersales volumes). The logic runs as follows. As its specification is tightened, *PNW Other* can no longer absorb the same volume of high-damage wheat. This forces some high-damage (and high-vomitoxin) wheat into other market segments. Such wheat can be sold in premium markets (i.e., *Domestic Milling* and *PNW Korea*) after appropriate blending, but average quality in those markets will decline. In fact, expected vomitoxin levels increase in shipments to premium markets as *PNW Other* tightens its damage specification (Table 8). With fixed contract prices, this reduces the probability of satisfying requirements and hence the expected price received in premium markets. As a result, prices received in *PNW Other* become more attractive in relative terms, inducing larger sales.

In practice, changes in specifications by one buyer may lead to changes by other buyers. Thus, tightening of specifications by *PNW Other,* and the consequent redirection of high-damage grain to other market channels, could induce changes in bid prices or quality discounts by premium markets. Such interactions are not captured in our model, although the results do suggest different possible forms of strategic response.

SUMMARY AND DISCUSSION

Quality variability is a major concern of grain importers and domestic processors and, consequently, has implications for merchandisers and farmers. For spring-planted grains in North America, the importance of quality variability was heightened in 1993 and 1994. Untimely rains in those years increased the level and variability of vomitoxin. This is an undesirable characteristic subject to food safety concerns and regulations and has been cited as a problem in both domestic and world market channels.

Characteristics like vomitoxin are not easily controllable through contracts, due to sampling difficulties (and expense) and measurement error. As a result, traders and end-users can be exposed to significant quality risks. These types of problems are found in wheat, barley and corn (aflatoxin).

Confronted with severe quality uncertainty, grain markets can respond in several ways. Large premiums and discounts can emerge, having the effect of disrupting normal spatial flows. In the case of vomitoxin in spring wheat, some importers responded by a tightening of contract specifications or by offering premiums for shipments with reduced vomitoxin. Domestic processors, in competition with importers, responded similarly. In this trading environment, merchandisers confront several sources of risk. One is the risk of not being able to meet specifications and having to sell at a discount (i.e., in a secondary market). The other is the risk of paying too high a price for wheat based on false expectations. In 1993, farmers expressed concerns about large discounts for damaged or infected wheat delivered to country elevators.

We developed a mathematical programming model to analyze this problem. The model incorporates spatial dimensions of quality distributions, competing geographic market demands, and contract requirements and prices for specific buyers. One of the important features is that probabilities (i.e., of satisfying constraints for vomitoxin) are endogenous; implicitly, they reflect price signals

received by traders. The model was used to evaluate the effect of quality distributions and alternative buyer strategies on spatial flows and grain values in country locations.

Simulations were conducted using market data and grain quality distributions for 1993 (the base case) and 1994. For illustration, we varied the level and standard deviation of vomitoxin and simulated different procurement strategies (prices and contract specifications) by principal buyers of spring wheat. Following are some of the important results and implications:

- Flows in the base case (1993) are primarily to the *Domestic Milling* market and to the *PNW Other* and *PNW Korea* contracts. Flows to Japan are nil due to abnormally tight specifications on vomitoxin relative to supply and competing contracts. Shadow prices varied substantially across contiguous regions, reflecting differences in the level and variance of vomitoxin and other characteristics. An additional simulation was performed for the 1994 crop year; flows and shadow prices varied substantially from the base case.

- The model was used to evaluate the relative importance of the mean level and variance of vomitoxin on shadow prices of wheat in a particular producing region (CRD5). Results demonstrate that increases in either the mean level or variance have a negative effect on prices. Thus, merchandisers, farmers and breeders should be concerned with both the mean value of an undesirable characteristic and with its variance.

- Buyers' procurement strategies are reflected in contract specifications and in the use of premiums and discounts for particular quality characteristics. In evaluating these alternatives, buyers have to be cognizant of the spatial dimension of competition and competition from other buyers. Specifying abnormally tight requirements, not matched by competing contracts, reduces the geographical region in which a buyer is competitive. However, in the context of our model, with multiple quality factors and competing contracts, the effects of contract tightening are not always easy to anticipate. For example, by reducing the allowable limit for damage in one contract (*PNW Other*), we induced larger sales under this contract at the expense of sales to other, premium buyers.

The results illustrate complex interactions among prices, contract specifications, merchandising risks, and the importance of having secondary contracts in quality-differentiated markets. These features of the marketing environment are critical to merchandising decisions and to an informed understanding of spatial flows and quality-related price spreads.

REFERENCES

Adam, B.D., P. Kenkel, and K. Anderson. 1994. "The Economics of Cleaning Winter Wheat for Export: An Evaluation of Proposed Federal 'Clean Grain' Standards." *Journal of Agricultural and Resource Economics* 19(December): 280-298.

Barry, P.J., P. N. Ellinger, J.A. Hopkin, and C.B. Baker. 1995. *Financial Management in Agriculture.* Danville, IL: The Interstate Printers and Publishers, Inc.

Flaskerud, G. 1993. Personal Communication, Department of Agricultural Economics, North Dakota State University, Fargo.

Fridirici, R., H.L. Kiser, L.D. Schnake, and J.A. Wingfield. 1984. *A View of the Economics of Removing Dockage From Wheat.* Manhattan: Kansas Agricultural Experiment Station, Contribution No. 84-342-D.

Hill, L.D. 1990. *Grain Grades and Standards: Historical Issues Shaping the Future.* Urbana: University of Illinois Press.

Hyberg, B., M. Ash, W. Lin, C. Lin, L. Aldrich, and D. Pace. 1993. *Economic Implications of Cleaning Wheat in the United States.* Washington, DC: USDA, Commodity Economics Division, Economic Research Service, Agricultural Economics Report No. 669, December.

Hyslop, J. D. 1968. *Price-Quality Relationships in Spring Wheat.* Department of Agricultural Research Report, University of Minnesota, Minneapolis.

Johnson, D. and W. Wilson. 1993. "Wheat Cleaning Decisions at Country Elevators." *Journal of Agricultural and Resource Economics* 18(December): 198-210.

Johnson, D. and W. Wilson. "Evaluation of Price/Dockage Strategies for U.S. Wheat Exports." *Review of Agricultural Economics* (forthcoming, May 1995).

Larue, B. and H. Lapan. 1992 . "Market Structure, Quality and World Wheat Market." *Canadian Journal of Agricultural Economics* 40: 311-28.

Lin, W. and M. Leath. 1993. *Costs and Benefits of Cleaning U.S. Wheat: Overview and Implications.* Washington, DC: USDA, Commodity Economics Division, Economic Research Service, Agricultural Economics Report No. 675, December.

Mercier, S. 1993. *The Role of Quality in Wheat Import Decisionmaking.* Washington, DC: USDA, Commodity Economics Division, Economic Research Service, Agricultural Economics Report No. 670, December.

Mercier, S. and B. Hyberg. 1995. "Grain Quality Revisited," *Choices* (first quarter): 35-38.

Milling and Baking News. 1993. *F.D.A. Withdraws Vomitoxin Advisory Level for Wheat.* P. 11, September 21.

Minnesota Wheat Research and Promotion Council. 1993. *Proceedings of the 1993 Scab Forum.* Moorhead, MN.

Minnesota Wheat Research and Promotion Council. 1994. *Proceedings of the 1994 Scab and Research Forum.* Fargo, ND.

Moore, Wayne R. 1994. Personal communication. Department of Cereal Chemistry, North Dakota State University, Fargo.

National Grain and Feed Association. 1993. "Vomitoxin: FDA Eliminates Vomitoxin Advisory Level for Raw Wheat; Increases Levels for Feed." *Milling Journal,* p. 6, October/November/December.

North Dakota Agricultural Statistics Service. 1994. *North Dakota Agricultural Statistics 1994.* Fargo: North Dakota State University, U.S. Department of Agriculture.

North Dakota Agricultural Statistics Service. 1995. *North Dakota Agricultural Statistics 1995.* Fargo: North Dakota State University, U.S. Department of Agriculture.

North Dakota State Wheat Commission. 1994. "Wheat Producers Facing Discounts." *Dakota Gold,* Vol. 11, No. 8, p. 1-3, September/October.

Oades, J . 1993. Personal communication, U.S. Wheat Associates, Portland, OR.

Pedrazza, J.M. 1994. "Scab Savvy Elevators Pay More for Grain." *Agweek,* p. 7, August 15.

Schreuben, L. 1968. "Systems Approach to Marketing Efficiency Research." *American Journal of Agricultural Economics,* 50 (2): 1454-1471.

St. Pierre, N.R. and W.R. Harvey. 1986. "Incorporation of Uncertainty in Composition of Feeds into Least-Cost Ration Models. 1. Single-Chance Constrained Programming." *Journal of Dairy Science* 69(December): 3051-3062.

U.S. Congress Office of Technology Assessment. 1989. *Grain Quality in International Trade: A Comparison of Major U.S. Competitors.* Washington DC: Office of Technology Assessment, F-402.

U.S. General Accounting Office. 1993. *Midwest Grain Quality,* GAO/RCED-94-66R (B-255567).

Veeman, M. 1987. "Hedonic Price Function for Wheat in the World Market: Implications for Canadian Wheat Export Strategy." *Canadian Journal of Agricultural Economics* 35 (November): 535-52.

Wahl, T. and A. D. O'Rourke. 1994. "The Economics of Sprout Damage in Wheat." *Agribusiness,* 10(1): 27-42.

Waugh, F.V. 1942. "Regressions Between Sets of Variables." *Econometrica,* 10: 290-310.

Wheeler, M. 1994. "Malting Industry Rejecting Barley with Vomitoxin." *The Forum*, Sec. A, p. 6, October 6.

Wilson, W. 1989. "Differentiation and Implicit Prices in Export Wheat Markets," *Western Journal of Agricultural Economics* 14(July): 67-77.

Wilson, W. 1994. "Demand for Wheat Classes by Pacific Rim Countries." *Journal of Agricultural and Resource Economics* 19(July): 197-209.

Wilson, W. and P. Gallagher. 1990. "Quality Differences and Price Responsiveness of Wheat Class Demand." *Western Journal of Agricultural Economics* 15(December): 254-264.

Wilson, W. and T. Preszler. 1991. "End-Use Performance Uncertainty and Competition in International Wheat." *American Journal of Agricultural Economics* 74(August): 556-563.

Wilson, W., D. Scherping, D. Johnson, and D. Cobia. 1992. *Impacts of Alternative Policies Regulating Dockage.* Agricultural Economics Report No. 285, North Dakota State University, Fargo, May.

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